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Performance of RASS Vortex Detection/ Measurement System

Research and
Special Programs
Administration
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PREFACE

This report was prepared by the Surveillance and Sensors Division of the Office of Traffic and Operations Management at the John A. Volpe National Transportation Systems Center for the Federal Aviation Administration (FAA). Its purpose was to analyze and validate the longitudinal and transverse mode Radio Acoustic Sounding System (RASS) capabilities: to indicate vortex presence in the flight path during a variety of meteorological conditions; and to track a vortex or pair of vortices during a variety of meteorological conditions.

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1. INTRODUCTION

Preliminary tests conducted by WLR Research in the Fall of 1993 showed considerable promise that a Radio Acoustic Sounding System (RASS) was capable of detecting and tracking wake vortices located in the approach glide slope. Initial testing of the RASS created interest in the possibility of a relatively low cost RASS monitoring the entire approach glide slope out to the middle marker. As a result of the optimistic results of the initial tests, the Federal Aviation Administration (FAA) Wake Vortex Program Office decided to fund additional testing of the RASS to resolve some remaining questions and to evaluate its performance in detecting wake vortices in both the longitudinal (along the approach path) and transverse (perpendicular to the approach path) modes. The questions to be resolved were:

- Were the signal losses which occurred when aircraft arrived actually related to wake vortices?

- Signal losses in the RASS were also noted when no aircraft had arrived. How reliable is vortex detection relative to the natural variation in RASS signal levels?

- Similar signal losses, both in magnitude and duration, were noted for all sizes of aircraft. Is there enough correlation between RASS signals and the vortex strength to make a reliable and efficient vortex avoidance system?

The test site for this demonstration was the approach corridor to runway 31R at JFK International Airport. The John A. Volpe National Transportation Systems Center (Volpe Center) leased the RASS hardware and software from NOAA/ERL/ETL for WLR Research to use in the test. In addition, the Volpe Center installed a Ground Wind Vortex Sensing System (GWVSS) for use as truth data in order to verify the RASS technique for detecting vortices.

The GWVSS, which comprises a line of two-axis anemometers atop 30-foot poles, can track the lateral position of the wake vortices over $\pm$ 350 feet from the extended runway centerline. Figure 1 shows the equipment configuration at JFK.

The RASS principle of operation involves the generation of acoustic pulses along a line of sight and bouncing radar pulses off the acoustic wavefronts during their passage. In actual operation, a single RASS antenna was pointed up the approach glide slope; after an aircraft arrived, the RASS signal appeared to drop for a time corresponding to the duration of the wake vortices in the RASS beam.

The purpose of this test program was to validate the longitudinal and transverse mode RASS capabilities to:

- Indicate vortex presence in the flight path during a variety of meteorological conditions.

- Track a vortex or pair of vortices during a variety of meteorological conditions.

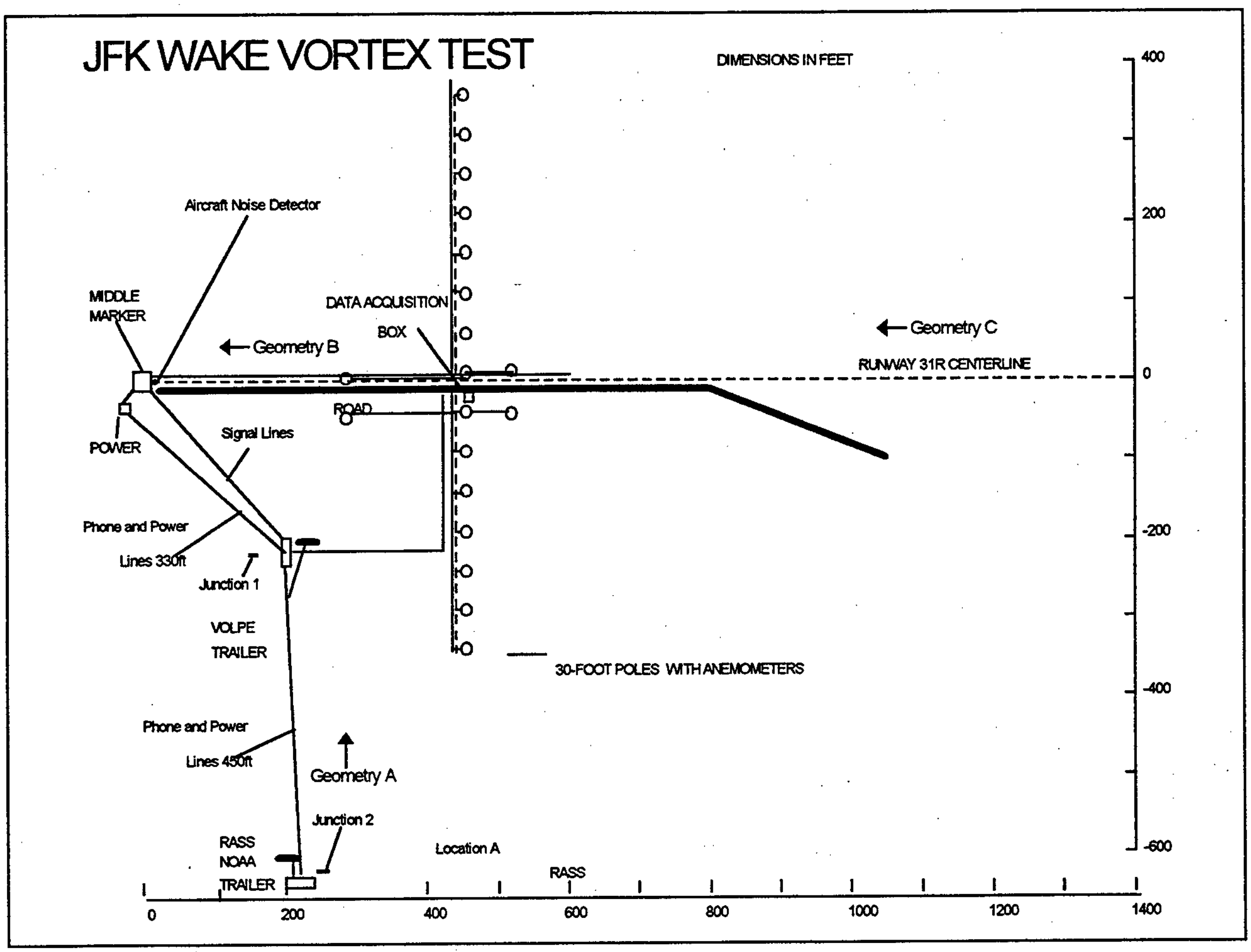


Figure 1. Kennedy Airport Vortex Test Site: Middle Marker Region of Runway 31R

2. TEST PLAN

The use of the GWVSS line as reference sensor for vortex location suggested a RASS geometry, Geometry A, where the RASS looks transverse to the aircraft flight path. In this geometry the RASS monitors a single cross section of the glide slope.

The primary configuration of the test plan was to employ the longitudinal mode where the RASS looks along the axis of the wake vortices. Two RASS locations were specified:

1) Geometry B, where the RASS is located under the glide slope near the middle marker.

2) Geometry C, where the RASS is located near the glide slope antenna. This geometry was used in the preliminary RASS tests.

3. DATA COLLECTION

3.1 RASS GEOMETRY

The field site is depicted in Figure 1. The GWVSS line was installed 400 feet inside the middle marker of Runway 31R. During the checkout phase, a number of RASS locations were utilized.

In the transverse RASS geometry, Geometry A, the RASS was located about 170 meters from the extended runway centerline. The normal elevation angle of the beam was 12 degrees. Limited data were collected at elevation angles of 9 and 15 degrees. The full radar beam width is 9 degrees at 3 db down from peak response and 18 degrees at 13 db down from peak response. The range gates are spaced by 60 meters. Range gate 2 is centered at about 180 meters range (range gate 3 at 240 meters and range gate 4 at 300 meters). Because of short range blanking, range gate 1 is shortened and centered at about 140 meters range. The height limits of the range gate centers are listed in Table 1.

Table 1. RASS Radar Beam Height Limits (meters) for 12-Degree Elevation Angle

Range Gate	Range (meters)	Lower Limits		Beam Center	Upper Limits	
		-13 db	-3 db		-3 db	-13 db
1	140	7	18	29	40	50
2	180	9	23	37	51	65
3	240	13	31	50	68	86
4	300	16	39	62	85	108

Figure 2 shows the geometry of the RASS beam and range gates provided by a WLR model simulation. Figure 2 includes calculated vortex trajectories for a crosswind that causes one vortex to stall near the extended runway centerline. The five range gates in Figure 2 are not consistent with range gates listed in Table 1 due to ongoing modifications made to the field experiment. Doppler detection of vortices by the RASS in the transverse mode was demonstrated early in the test program; consequently, more emphasis was placed on this mode than the longitudinal mode during the remainder of the test program.

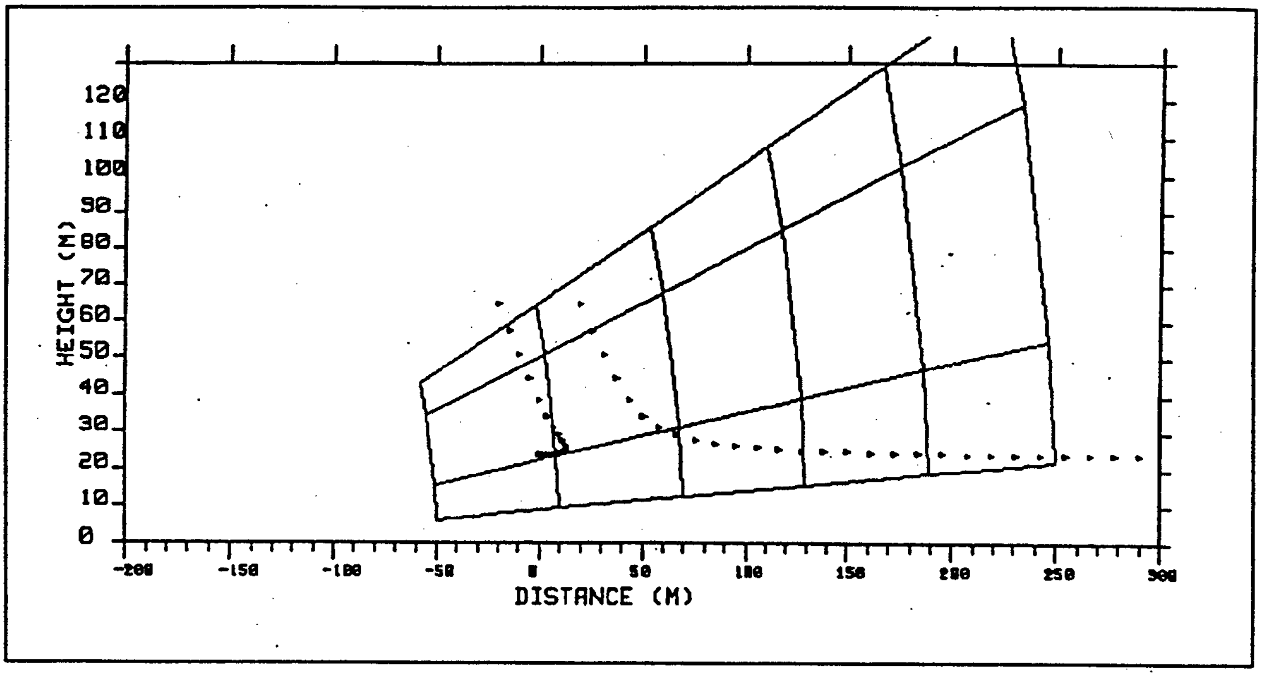


Figure 2. RASS Beam Geometry with Calculated Vortex Trajectories for Crosswind = 1.35 m/s

Source: WLR

As illustrated in Figure 2, the wake vortices are generated at the upper edge of range gate 2. The vortices descend toward the ground and then separate. If the vortices behave according to classical theory, their final height is half the initial separation. For range gates 3 and 4, the vortices will typically be below the main RASS beam for 12-degree beam elevation angle. At the conclusion of the experiment, it was determined that a 9-degree beam elevation angle was more desirable as it would correct this problem.

3.2 AVAILABLE DATA

RASS data were collected in the final transverse geometry (Geometry A) on the seven days listed in Table 2. The weather conditions included various combinations of crosswind and turbulence.

Table 2. Days for Transverse RASS Data

Date	Julian Day	Number Runs	Offset (sec)	Turbulence	Crosswind
10/20/94	293	31	1120	Low	Moderate away from RASS
10/21/94	294	25	1120	Low	Light
		43	1110	High	Strong away from RASS
11/11/94	315	31	1237	Low	Light away from RASS
11/13/94	317	74	1217	Moderate	Variable moderate crosswind
11/19/94	323	146	1155	Low/Mod.	Light/moderate away from RASS
11/22/94	326	69	1131	High	Moderate/strong toward RASS
12/3/94	337	71	1026	Low	Moderate toward RASS
	Total	490			

RASS data were collected in the longitudinal mode (Geometry C) on one day (12/28/94). Unfortunately, the GWVSS data collection system was down for this period. No data collected in Geometry B longitudinal mode were provided.

3.2.1 RASS Data Format

The RASS was operated by WLR personnel who also identified the aircraft. The aircraft arrival was identified by the RASS skin hit. The RASS data were provided in the form of:

- Vortex detection plots which showed when the RASS vortex detection parameter rose above a selected fixed detection threshold that gave virtually no false alarms.
- Data files of vortex signature (every 2.7 seconds.
- Aircraft arrival times.
- Data recorded by a NOAA weather station deployed between the Volpe and RASS NOAA trailers.

3.2.2 GWVSS Data Format

The Volpe GWVSS operated automatically. Aircraft arrivals were detected by their noise. The GWVSS data consist of a fun file for each aircraft. The run files contain two-second averages of the vertical wind and crosswind at each anemometer location from ten seconds before aircraft arrival until the next aircraft arrival or 180 seconds later, whichever comes first.

4. EVALUATION OF TRANSVERSE RASS GEOMETRY

4.1 CORRELATING RASS AND GWVSS RUNS

Table 2 shows the number of RASS runs for each day. The corresponding GWVSS data files were identified by generating databases of RASS and GWVSS runs and run times (number of seconds since midnight) and looking for a clock offset for each day that lined up the runs to within ten seconds. On 10/21/94, data collection was carried out during two periods with slightly different offsets and significantly different weather conditions.

Of the 490 RASS runs listed in Table 2, GWVSS files were identified for 395. Table 3 shows the list of aircraft identifications provided for these RASS runs. Table 4 lists the aircraft identifications for the 95 RASS runs not matched by a GWVSS run. The overwhelming majority are small aircraft which were not detected by the GWVSS aircraft noise detector.

Table 3. Runs with Both RASS and GWVSS Data

Aircraft Type	Count	Aircraft Type	Count
707	1	AEROFLOT	2
727	33	AEROFLOT-767	1
727	1	CANDID	3
737	2	CONCORD	2
747	61	DC10	12
747-200	1	DC8	9
747-400	16	DC9	35
757	15	L1011	9
767	86	LEAR	1
767(757)	1	MID11	12
767_MALEV	1	QUAD	2
____	5	TWIN	53
____	1	TWIN	1
A300	14	TWIN-SHORTS	2
A330	4	VAC	3
A340	5	VASP	1

4.2 DATA COMPARISON

The RASS provides a vortex location by using four range gates. Generally, the location of the vortex within a range gate is a function of vortex age. The traditional GWVSS analysis estimates the lateral position of each vortex at the anemometer locations giving the highest and lowest values of crosswind. Because of the low RASS elevation angles, the RASS range is approximately equivalent to the GWVSS lateral position.

Table 4. RASS Runs with No GWVSS Data

Aircraft Type	Count	Aircraft Type	Count
747	1	LEAR	3
757	2	LEAR-JET	
767	3	MD11	1
____	3	QUAD	1
A300	2	SINGLE	1
A320	1	TWIN	68
A340	1	TWIN-EAGLE	1
CONCORD	1	TWIN-SMALL	1
DC8	1	TWIN-TW	1
DC9	1		
DC9	1		

A plotting format was developed to provide the desired intercomparison (see Figure 3 and the figures in the Appendix). The GWVSS vortex locations are plotted as squares and x's as a function of vortex age (seconds) and distance from the RASS antenna (meters). The edges of the four RASS range gates are outlined with solid lines. The RASS signals for each range gate are plotted as line segments with zero at the nearest edge of the range gate and 300 m^2/s at the farthest edge of the gate, 60 meters away (the shortening of range gate 1 is ignored). This plotting format shows how the RASS signals vary with vortex position.

The WLR analysis of the RASS data used a fixed vortex detection threshold which was set high to avoid false alarms under worst case conditions (high turbulence, as might be expected). This approach leads to many missed vortex detections. Consequently, the analysis was less restrictive and counted vortex detections whenever the RASS signal was significantly above the ambient signal level. This approach accounts for two limitations of the analysis:

1) The GWVSS cannot tell when the vortex is displaced vertically away from the RASS beam.

2) The GWVSS cannot tell whether a vortex has decayed from its initial strength.

4.3 DATA EVALUATION

The RASS and GWVSS data for all seven days were compared. The effectiveness of the RASS in detecting vortices in the longer range gates was strongly dependent upon the beam elevation angle. General results will be presented first followed by the specific results for the different elevation angles and the different weather conditions.

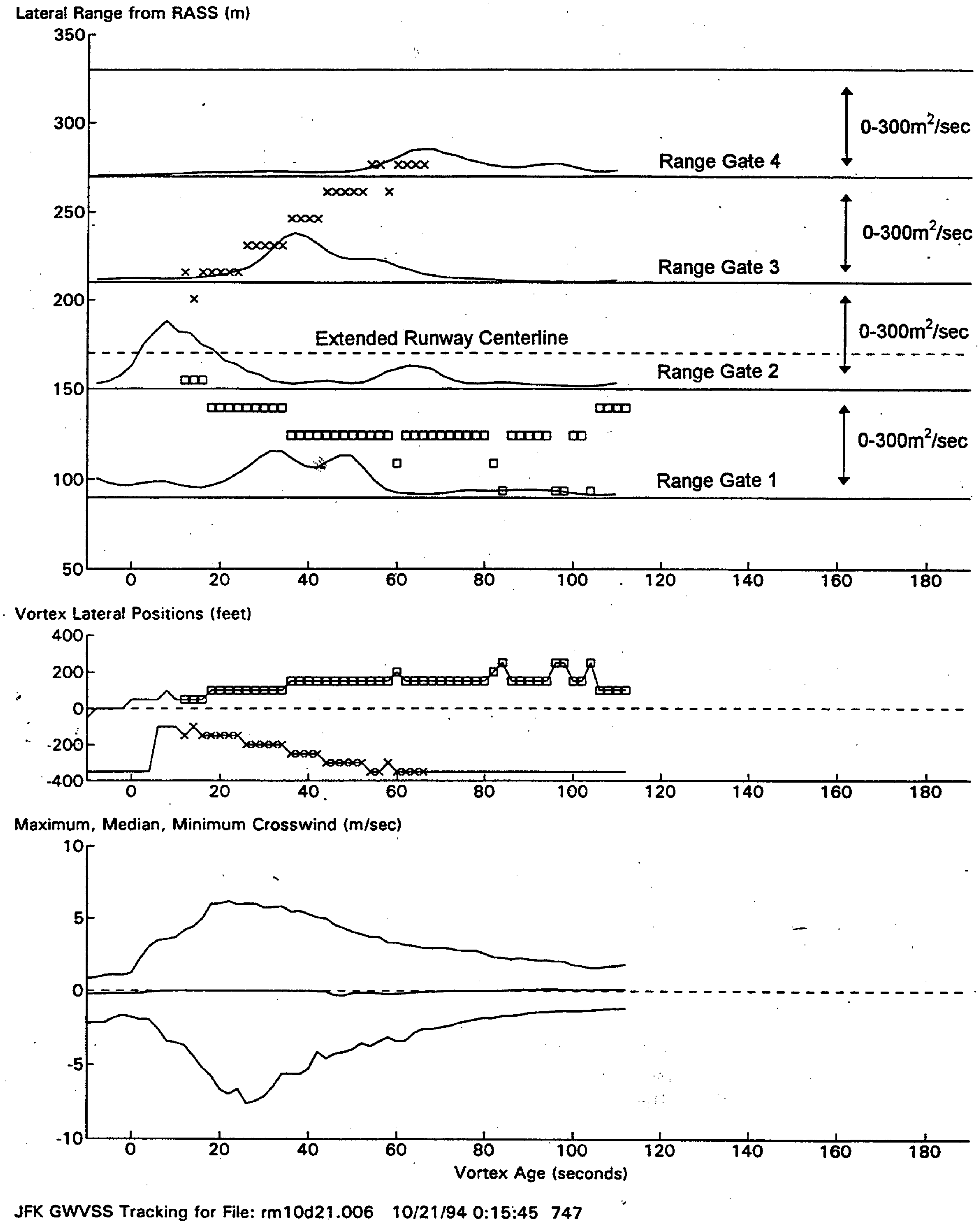


Figure 3. Comparison of RASS and Ground-Wind Line

4.3.1 General Results

- When RASS signals are observed for a particular range gate, the GWVSS locations are generally in or near that range gate.

- RASS signals are often not observed when the GWVSS location is within a particular range gate; particularly range gates 3 and 4 where the RASS beam may be well above the vortex location. This conclusion led the analysis to investigate different elevation angles in which WLR operated the RASS.

- The RASS signals rarely showed consistent decay, even when the vortex remains within a single range gate.

- The RASS background signals in the absence of wake vortices were significantly affected by turbulence, being much larger on high turbulence days. It should be noted that the GWVSS data were more affected by turbulence than the RASS. Only vortices from the largest aircraft could be detected by the GWVSS under high turbulence conditions.

4.3.2 9-Degree Results

The 9-degree data were collected under low turbulence conditions on 10/21/94 and showed optimal performance of both RASS and GWVSS. All the analysis plots for these cases are attached. The following results were obtained:

- Of the 19 GWVSS files associated with RASS runs, all except three twins gave usable GWVSS vortex locations. All 16 GWVSS runs gave significant RASS signals in range gates 1 and 2.

- The GWVSS data for 11 runs showed vortices in range gate 4; all were matched by RASS signals (weak in four cases).

- The GWVSS data for 15 runs showed vortices in range gate 3; all were matched by RASS signals (weak in one B-727 case and very weak in one DC-9 case).

- Three runs showed a RASS signals between the two vortices in a range gate with no vortices nearby.

- Three runs showed RASS signals in range gate 4 when the nearest vortex was well inside range gate 3. This response may represent secondary vortices generated by the interaction of the primary vortices with the ground.

4.3.3 15-Degree Results

The 15-degree data were collected under low turbulence conditions on 10/20/94 and showed good performance of the GWVSS but poor performance of the RASS in range gates 3 and 4. The following results were obtained.

- Of the 23 GWVSS files associated with RASS runs, all except four twins gave usable GWVSS vortex locations. All 19 GWVSS runs gave significant RASS signals in range 2. Only one gave a signal in range gate 1 since there was a significant crosswind away from the RASS during this test period.

- The GWVSS data for 16 runs showed vortices in range gate 4. Only one (767) showed significant RASS signals. Four (two 747s, two 767s) showed weak RASS signals.

- The GWVSS data for 19 runs showed vortices in range gate 3. Two (767s) showed significant RASS signals. Eight showed weak RASS signals and one a very weak RASS signal.

- Three runs showed a RASS signal between the two vortices in range gate with no vortices nearby.

- Three runs showed RASS signals in range gate 4 when the nearest vortex was well inside range gate 3.

The final two responses in this list may have been represented by secondary vortices generated by the interaction of the primary vortices with the ground.

4.3.4 12-Degree Results

In general, the 12-degree results under low turbulence conditions were intermediate between the 9- and 15-degree results. They are as follows:

- Vortices were detected in range gates 3 and 4, but not consistently. The detection probability was greater for larger aircraft (e.g., B-747) which have both larger circulations and greater vortex heights in ground effect.

- Vortices were consistently detected in range gate 2 except when a strong crosswind was blowing toward the RASS (11/22/94); in the latter case, vortices were consistently detected in range gate 1.

- False vortex detections were noted under high turbulence conditions; they were most noticeable in range gates 3 and 4 when the crosswind was blowing strongly toward the RASS (11/22/94). The RASS false detections were typically accompanied by some GWVSS false detections. Apparently, both systems were responding to the same wind turbulence. The strong false RASS detections had values above 100 m^2/s

and were associated with a TWIN aircraft run (RASS time 64170.1 seconds, GWVSS file rm11d22.088). False detections of about 90 m^2/s were noted for the RASS DC-9 run at 71304.9 seconds.

- One run (A330 at 67251.2 seconds on 11/13/94) showed unusual signals. Large RASS signals appeared in range gates 2, 3, and 4 which may represent the downwind vortex. The GWVSS picked up only the upwind vortex at much later times. Perhaps this run represented an abnormally high aircraft.

5. ANALYSIS OF LONGITUDINAL RASS DATA

The limited amount of longitudinal RASS data is complicated by a number of factors:

- The exact RASS geometry has not been defined.
- No GWVSS data were recorded on 12/28/94. In any case, the GWVSS would have measured vortex lateral positions far away from the RASS measurement region.

The RASS data collection period was 1710-2100 hours (GMT) (afternoon). Table 5 lists the surface observations for this period. A consistent crosswind of 8 knots (4 m/s) toward the RASS location was observed.

Table 5. JFK Surface Observations on 12/28/94

Time (GMT)	Temperature	Windspeed	Wind Direction	Crosswind	Headwind
1650	47 °F	9 kts	250°	7.8 kts	4.5 kts
1750	48	8	210	7.9	-1.4
1950	52	9	240	8.5	3.1
2050	49	9	250	7.8	4.5

Other results were:

- Significant signals were observed whenever jet transport aircraft arrived. Smaller aircraft did not generate consistent signals.
- The RASS was located along the side of the runway, perhaps 60 meters from the centerline. The RASS signals lasted typically 30 to 40 seconds. This duration is consistent with the expected vortex behavior.
- The upwind vortex would take the longest to pass the RASS. For the largest aircraft (B-747), it would have to travel about 90 meters to the RASS location. The crosswind would be opposed by the ground-induced motion of about 2 m/s; the net transport speed would therefore be about 4-2 = 2 m/s, leading to a maximum signal duration of about 45 seconds.
- RASS signals were observed mostly in range gates 2 and 3. Only the B-747 gave signals in range gate 4; this observation is consistent with the greater ground-effect height and size of the B-747 wake vortices.
- In one case, significant signals were observed with no indication of an aircraft arrival.

6. RASS OBSERVATIONS

6.1 TRANSVERSE MODE

The performance of the RASS appears to be dominated by its spatial coverage. It appears to detect consistently any wake vortices located inside its beam. The RASS may respond to other disturbances inside its beam:

- Secondary vortices and other products of the interaction of the wake vortices with the ground.
- Vortex-like turbulence structures.

6.2 LONGITUDINAL MODE

Vortices from jet transport aircraft appear to produce positive signals in contrast to the signal loss noted in the preliminary RASS test. Data collected was insufficient to establish the reliability of vortex detection.

6.3 VORTEX DETECTION ALGORITHM

The current RASS vortex algorithm appears to throw away considerable useful spectral information in order to obtain a scalar detection parameter. In transverse mode, the position of the vortex in the beam is likely signaled by the sign(s) of the Doppler shifts:

- A vortex centered in the beam will have Doppler shifts of both signs.
- A vortex to one side of the beam will have only one sign of Doppler shift.
- A vortex on the other side of the beam will have the other sign of Doppler shift.

Currently, WLR makes no attempt to identify which vortex is being detected. The sign of the Doppler shift for a vortex on the side of the beam identifies the vortex. Since the initial vortex positions and motion are known, the expected Doppler signs can be predicted for each vortex.

7. CONCLUSIONS

The following conclusions can be drawn about the demonstrated transverse-mode RASS capability for a wake vortex system:

- The RASS consistently detects the fresh vortices from Heavy and Large aircraft in light winds and Heavy aircraft in turbulent winds. Vortices from Large aircraft in heavy winds are less consistently detected.

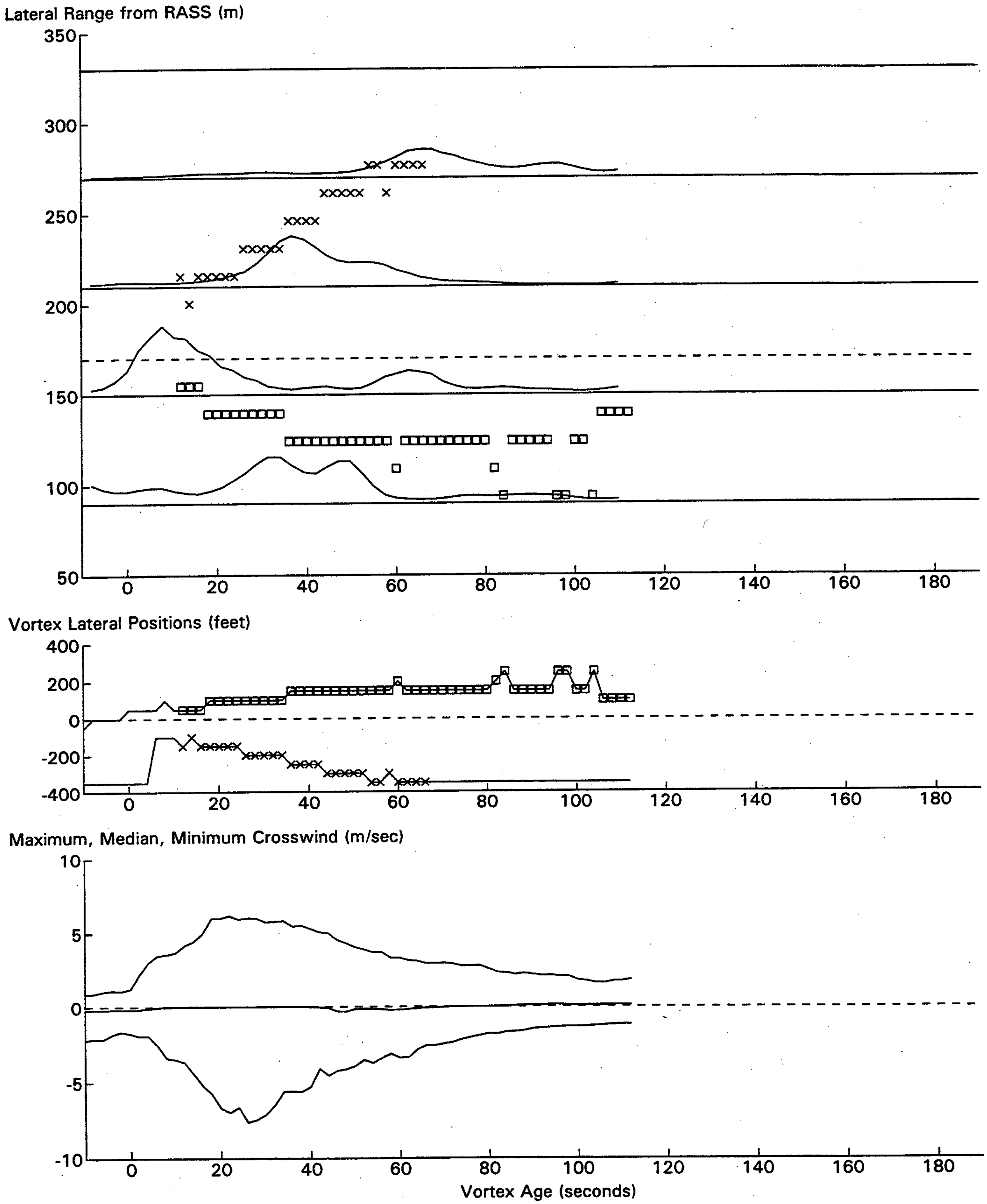
- The current test provides only limited information about the potential spatial coverage of a RASS for vortex detection, especially for takeoff operations. Only one configuration was extensively tested and it had limited coverage near the ground for distant range gates and hence often lost track of vortices. Lowering the beam elevation angle to get more complete coverage significantly improved performance. The maximum range capabilities of the RASS were not determined since no ranges beyond 330 meters were tested.

- The current transverse-RASS vortex detection algorithm provides limited information:

1) The position of the vortex in the beam is not estimated although such information would permit assessment of whether the vortex has died or has drifted out of the beam.

2) The vortex or vortices located in a particular range gate are not identified as starboard or port. The lack of such information reduces the reliability of vortex tracking.

Few conclusions can be drawn about the longitudinal-mode RASS capability for detection of wake vortices due to insufficient data.



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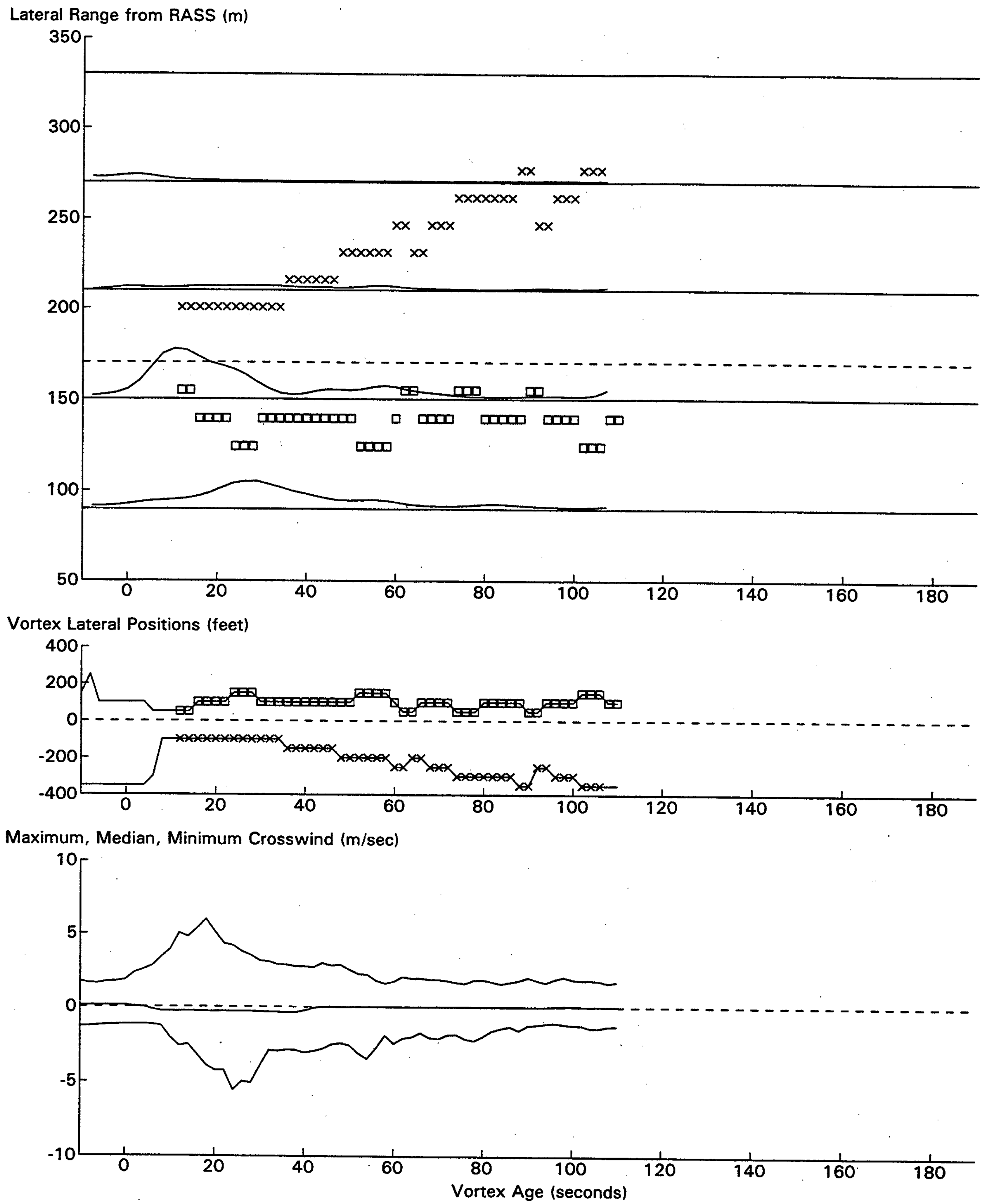

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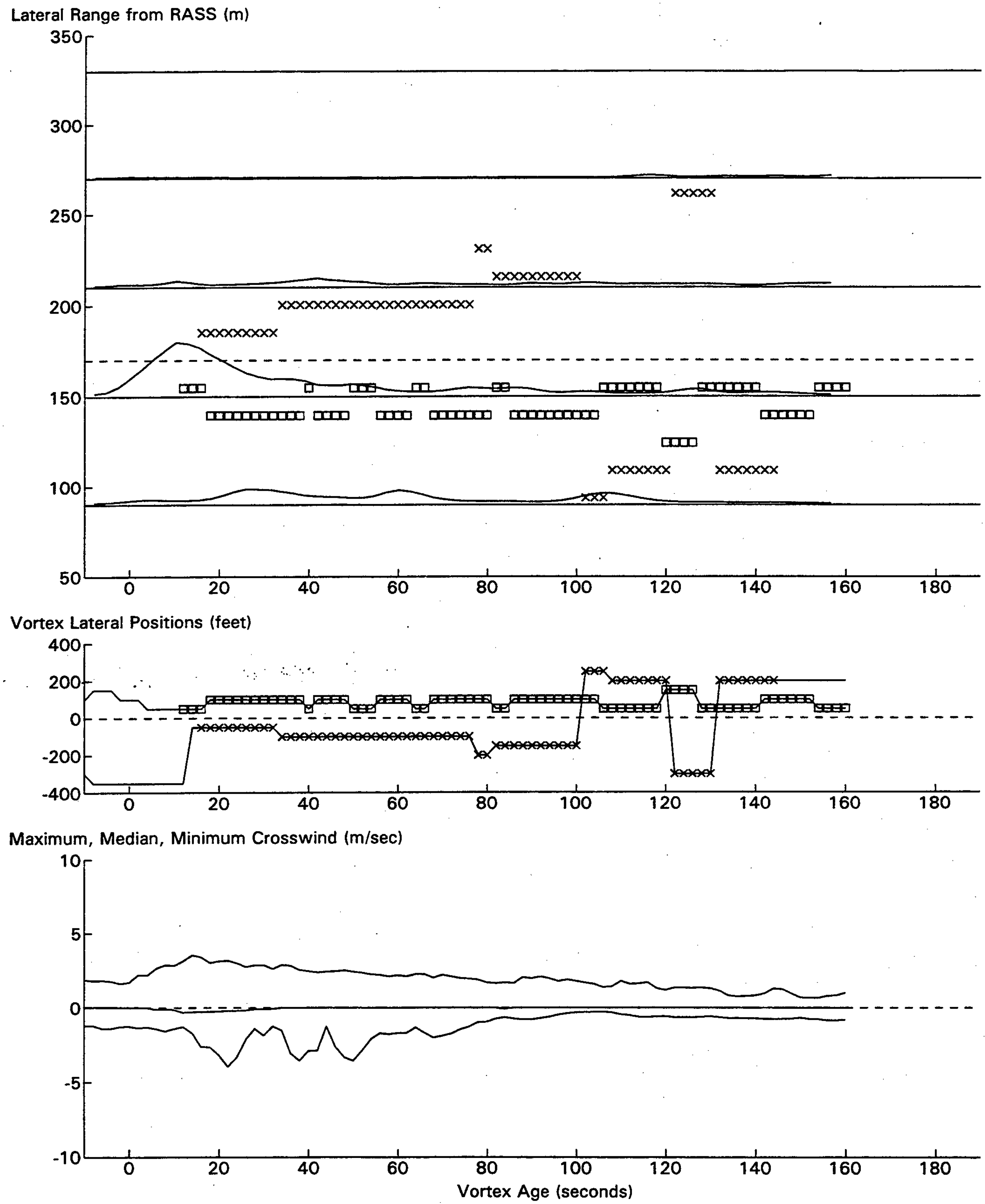

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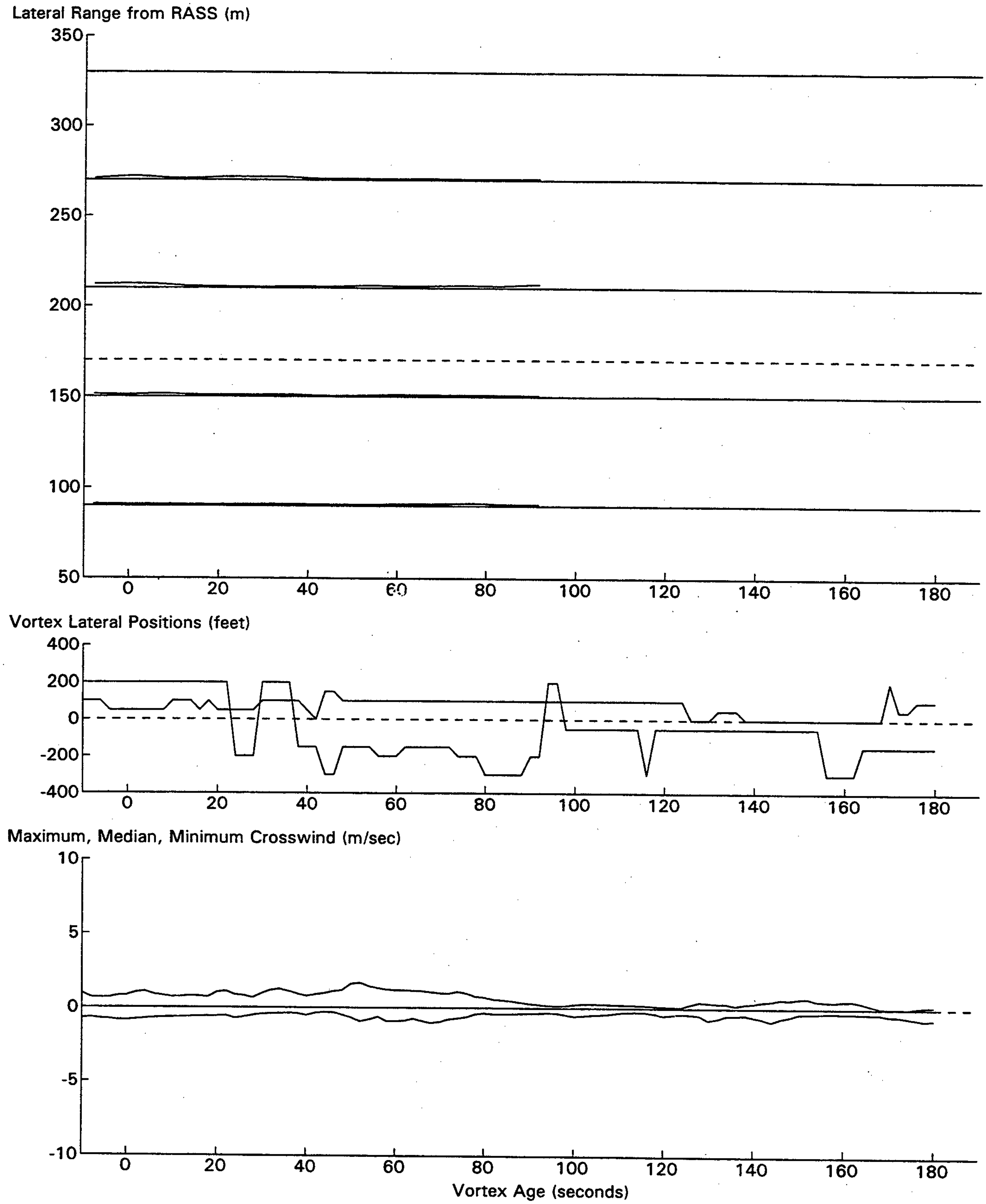

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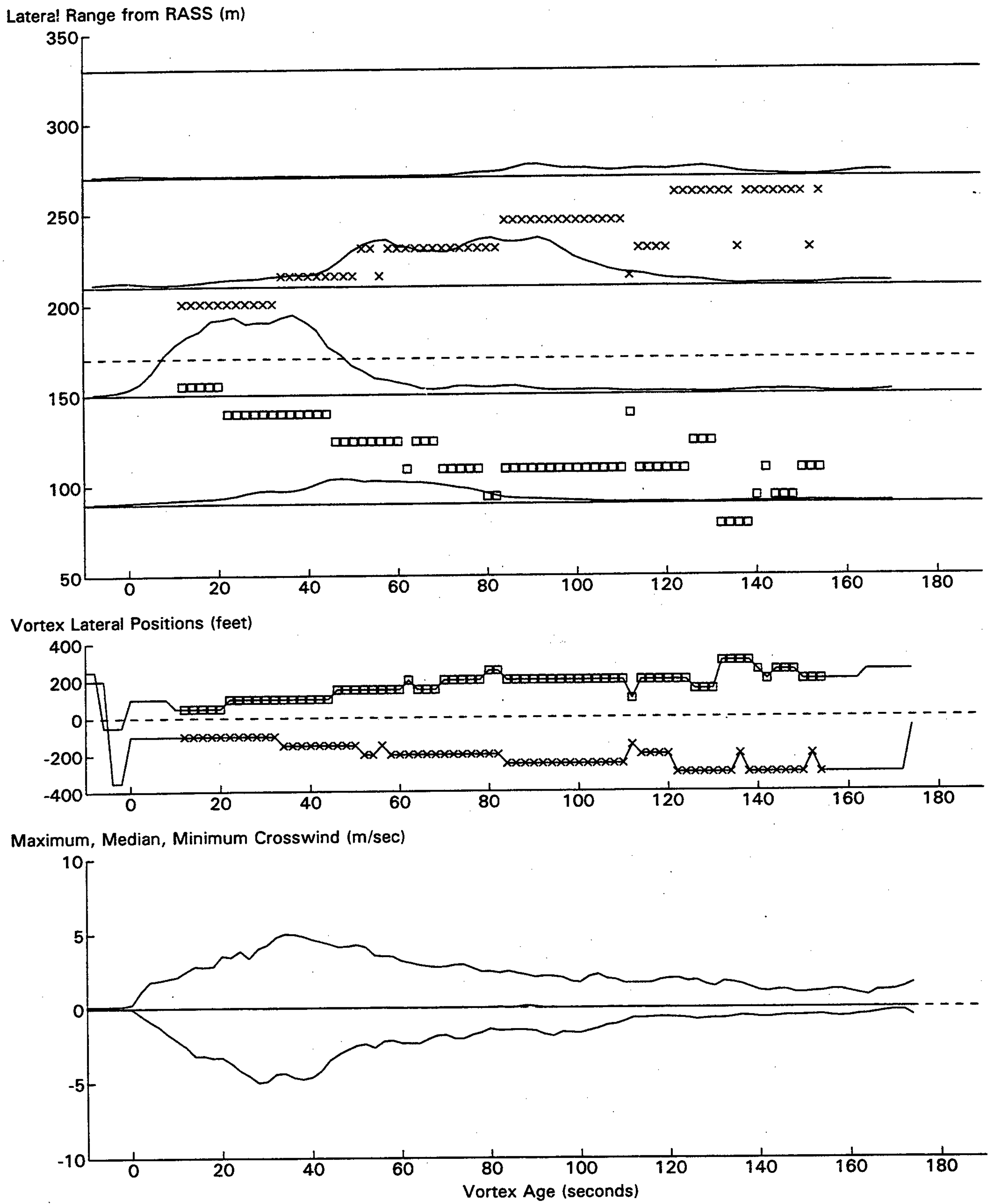

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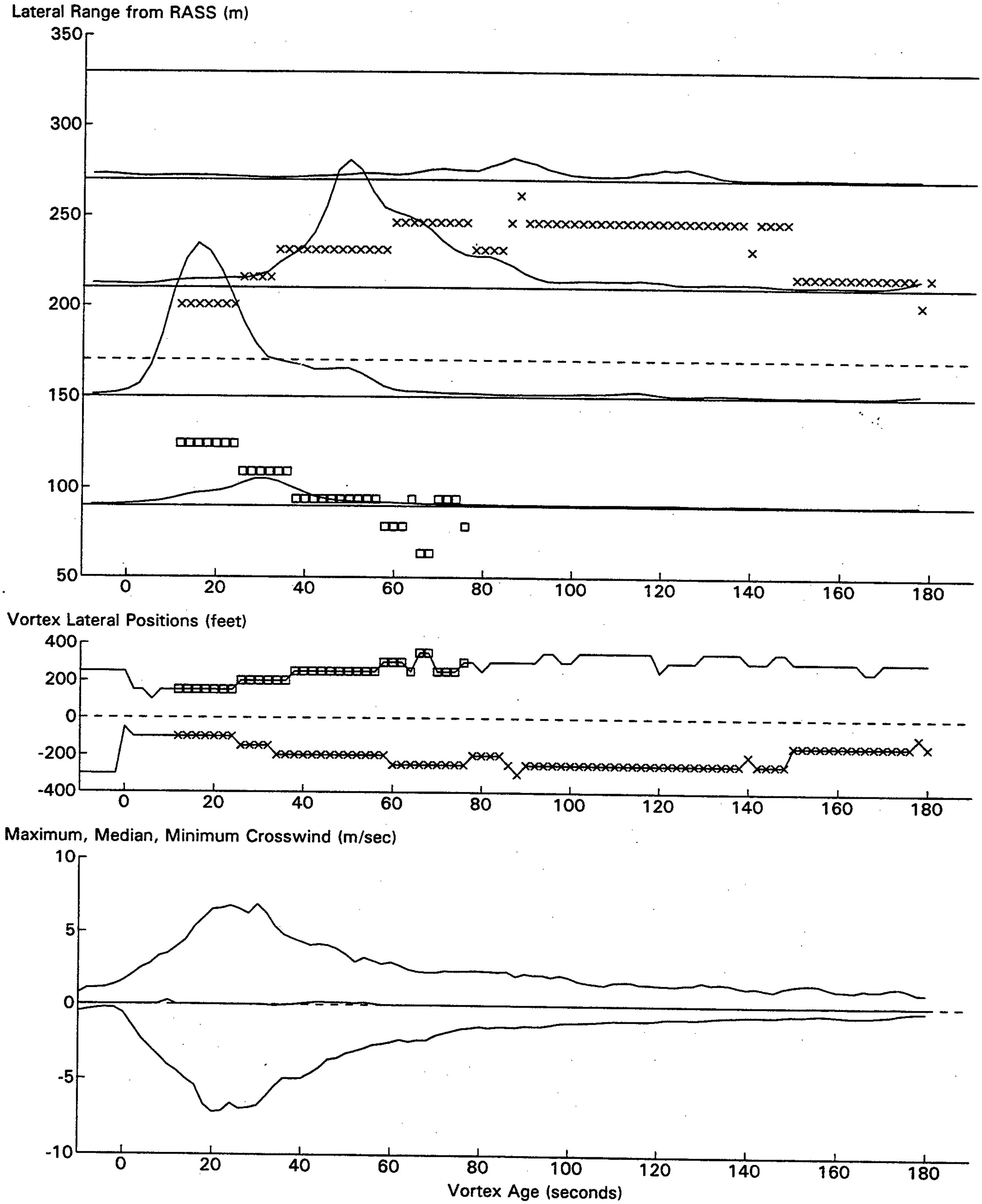

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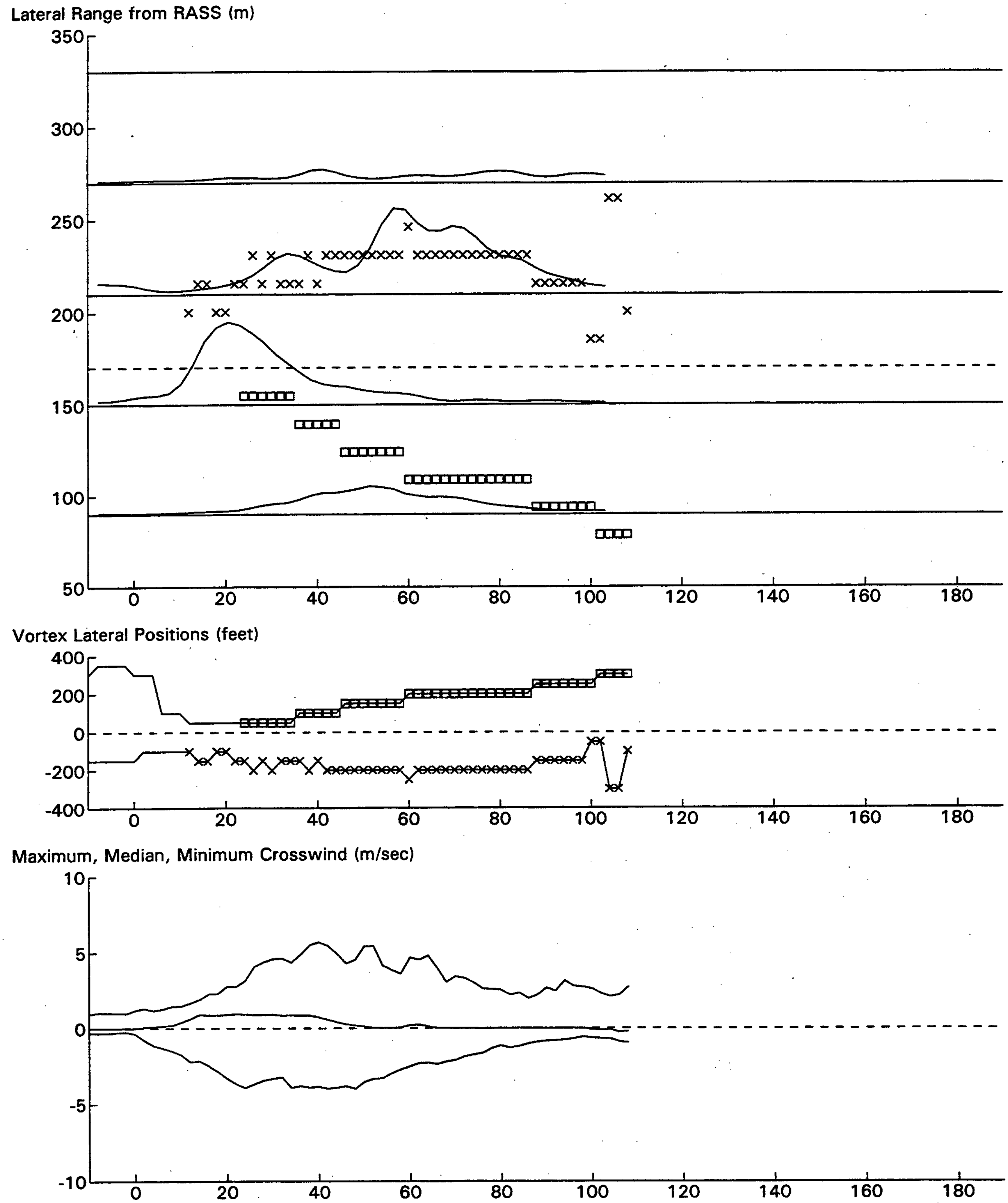

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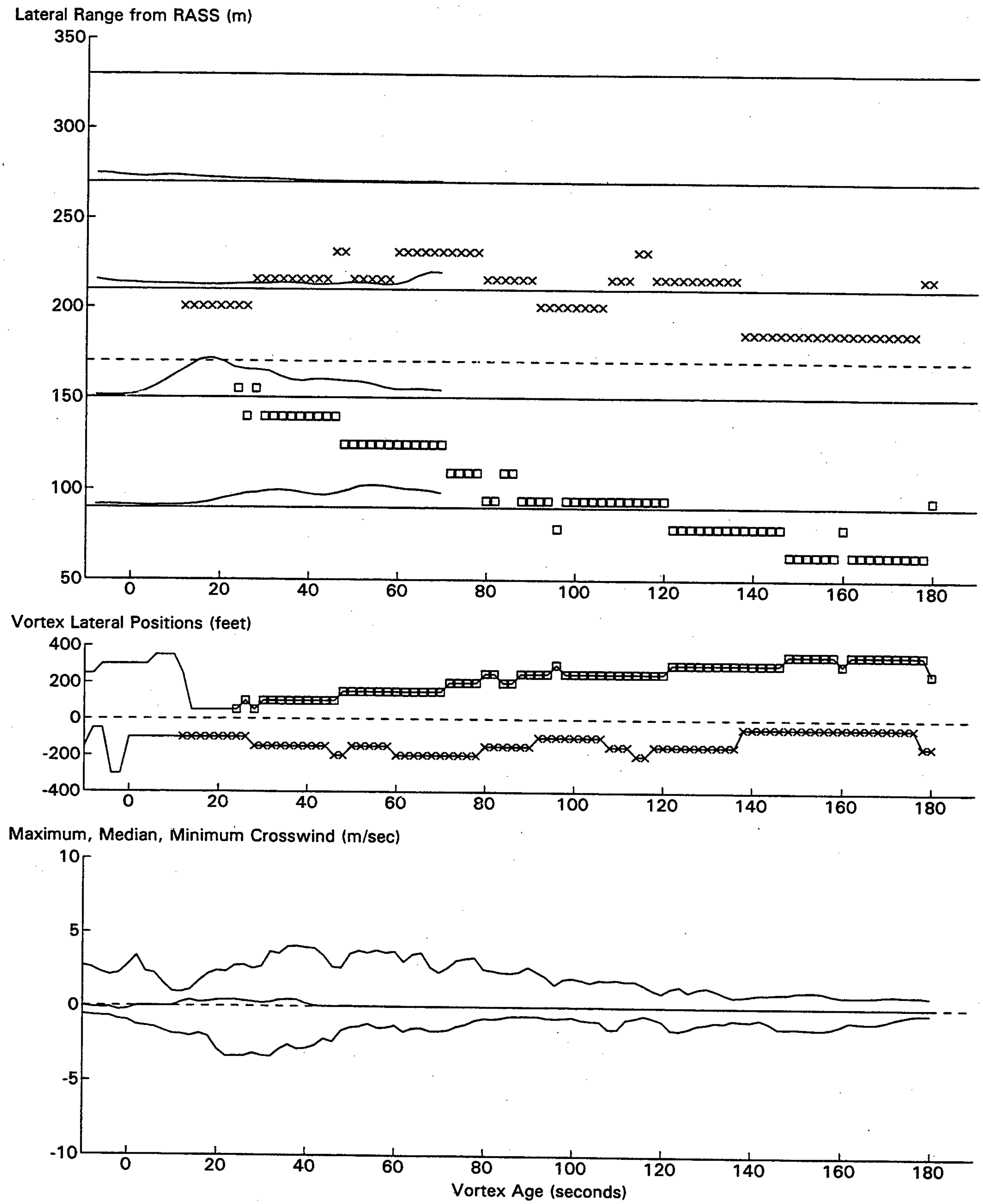

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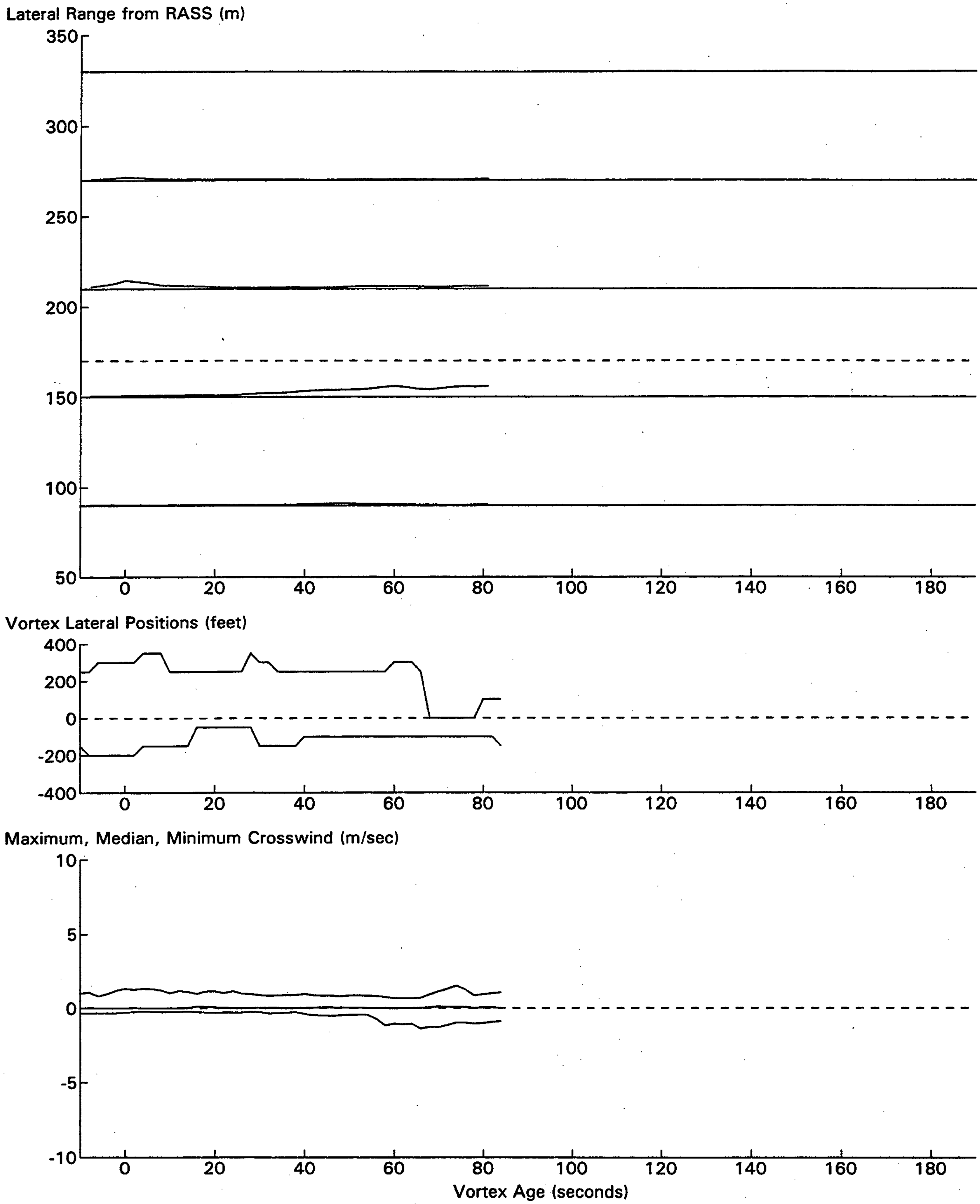

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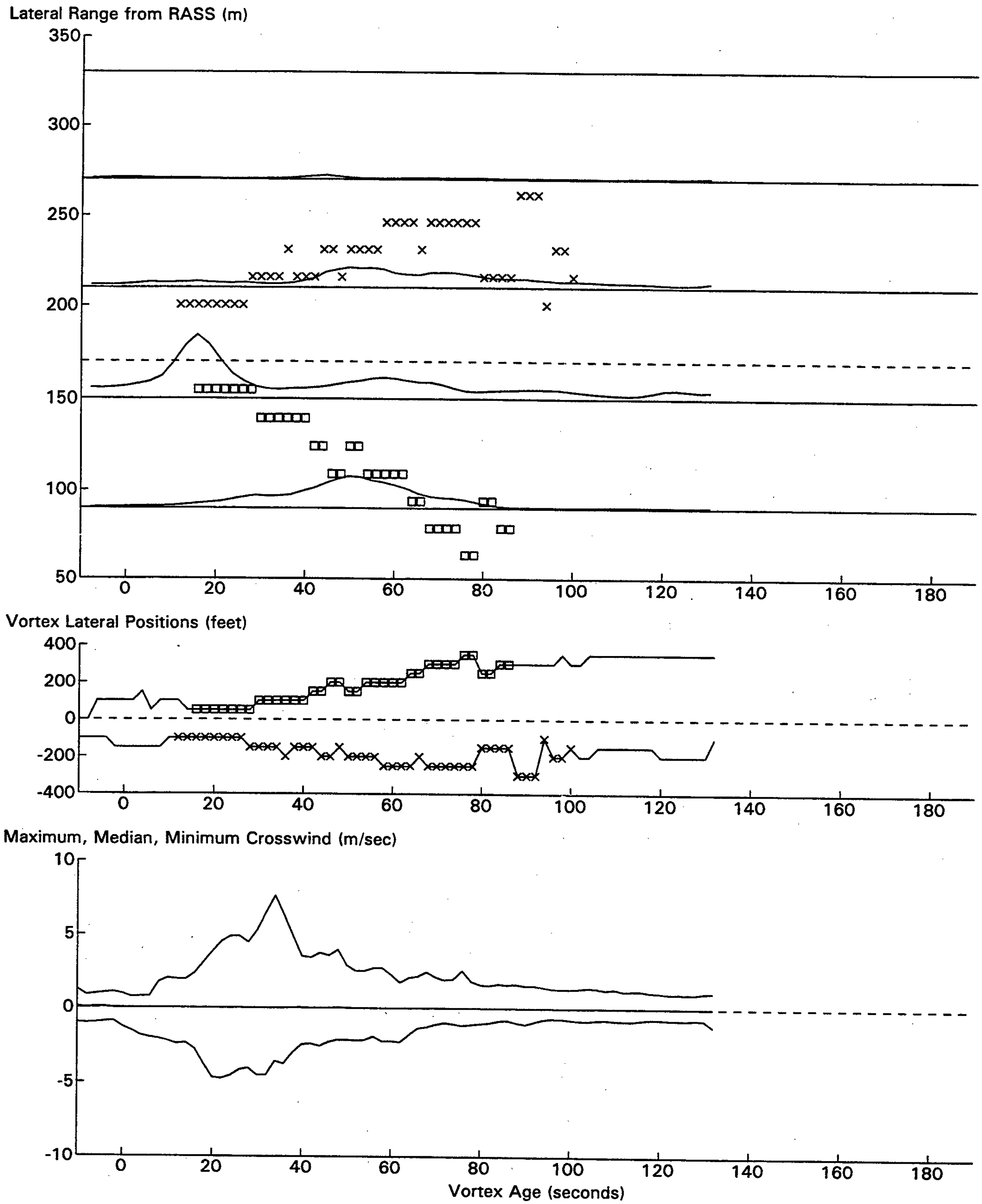

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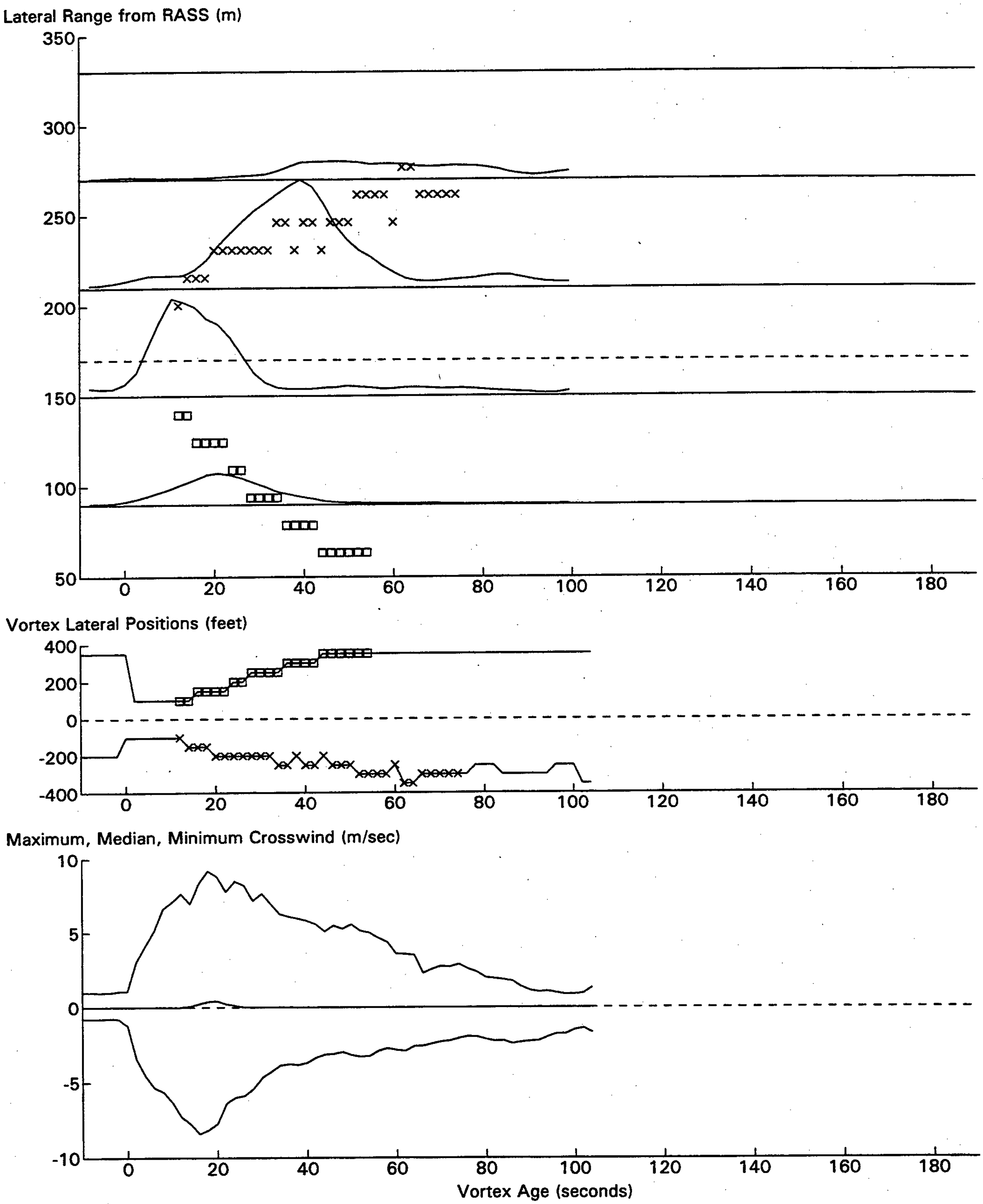

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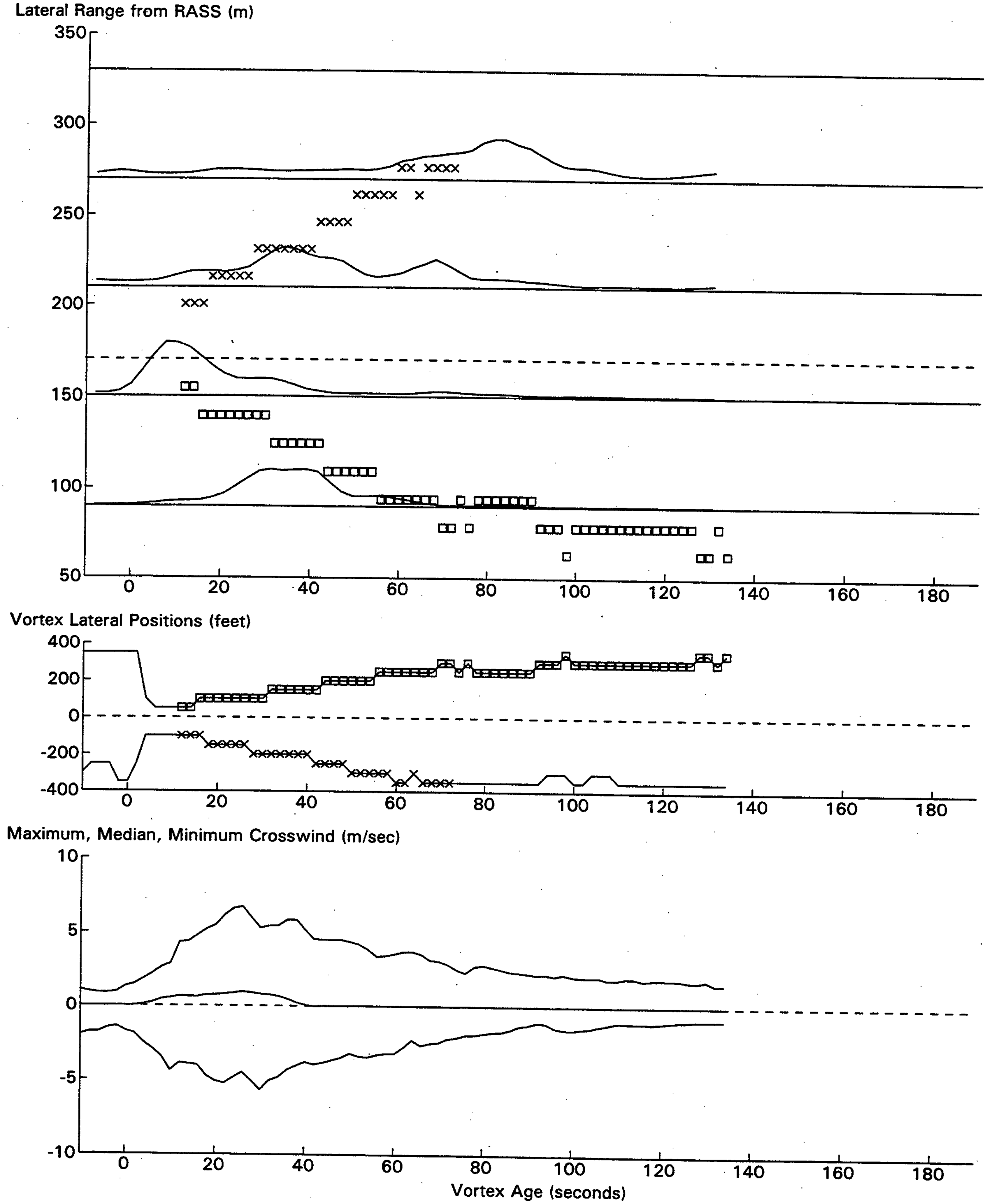

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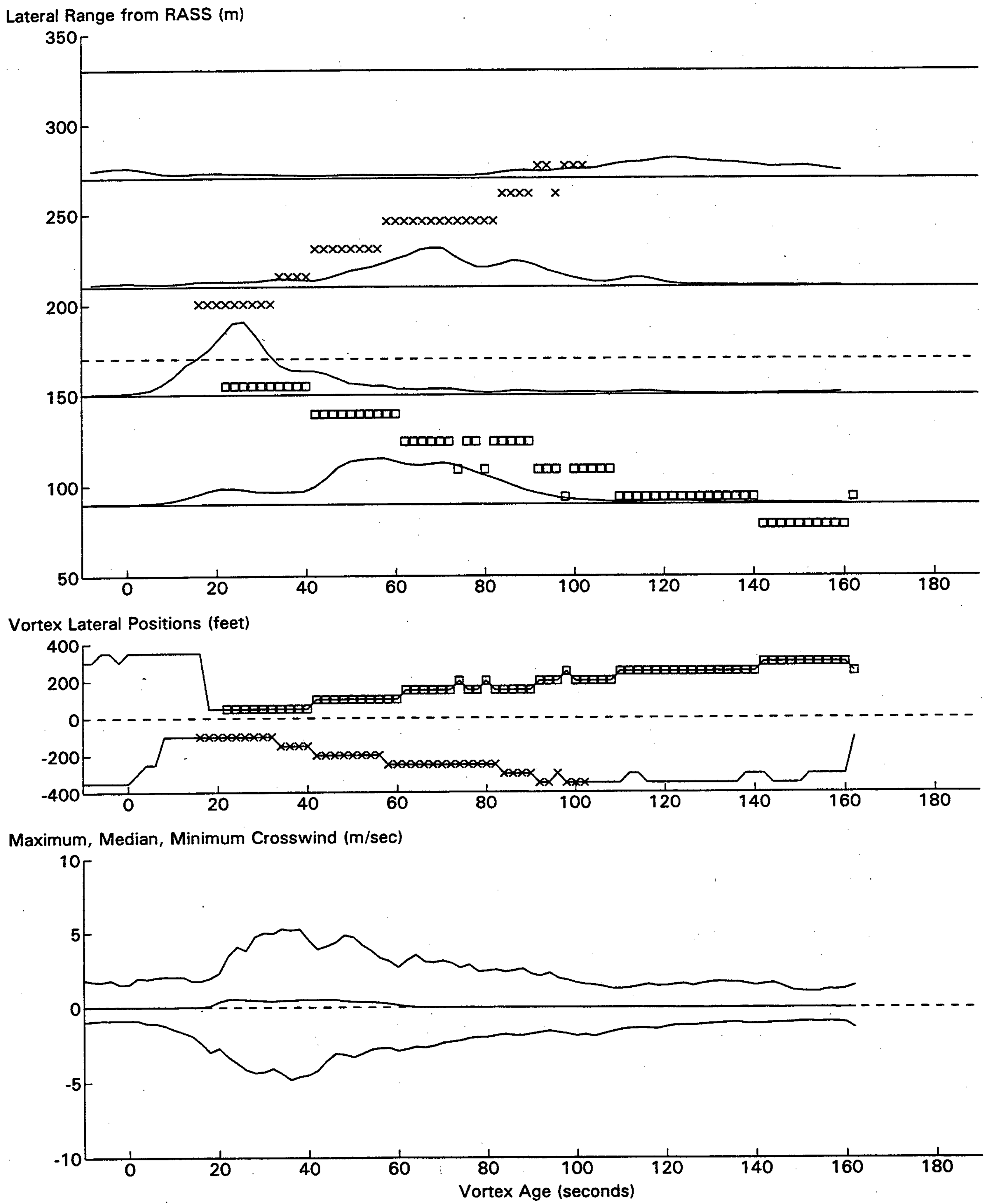

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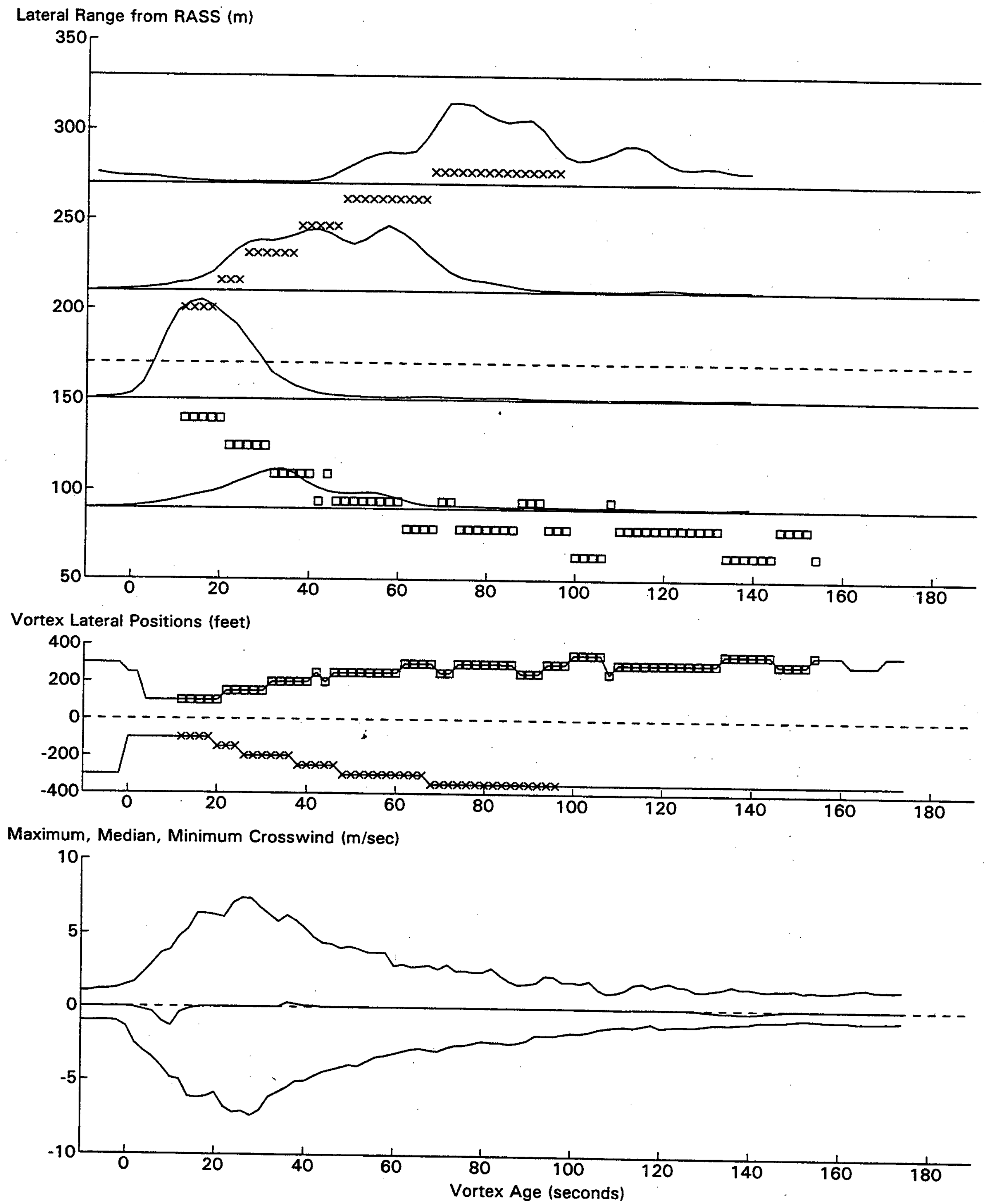

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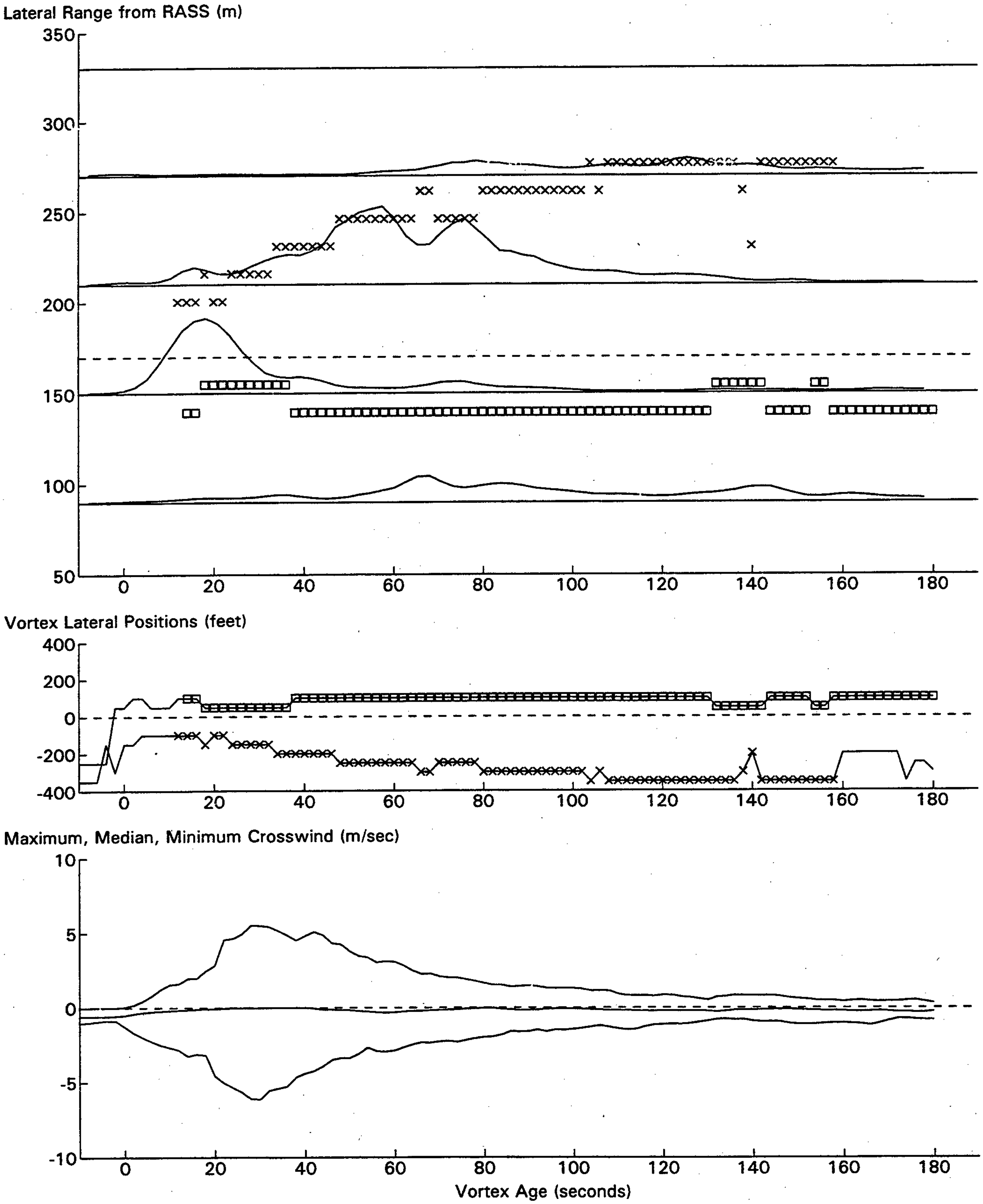

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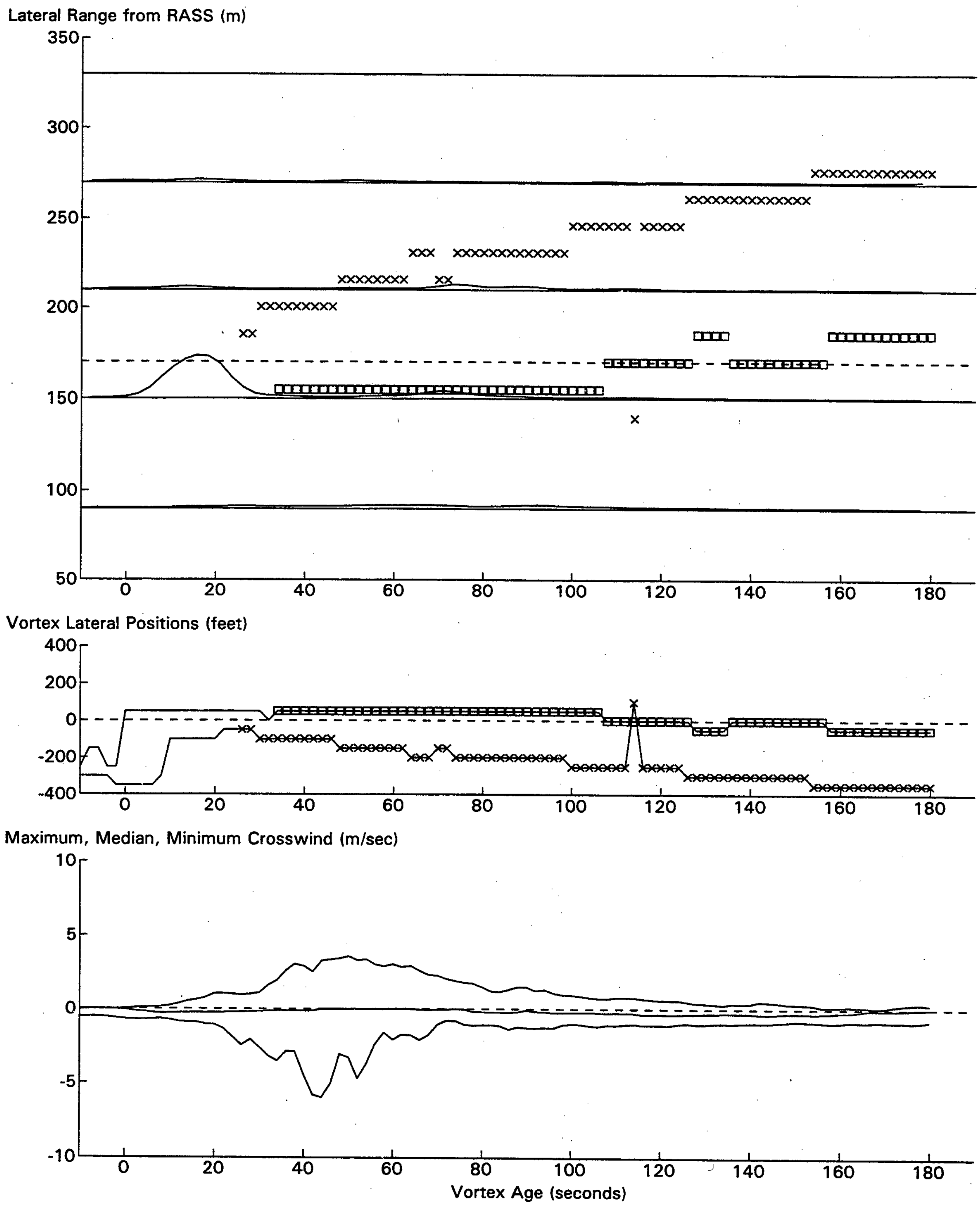

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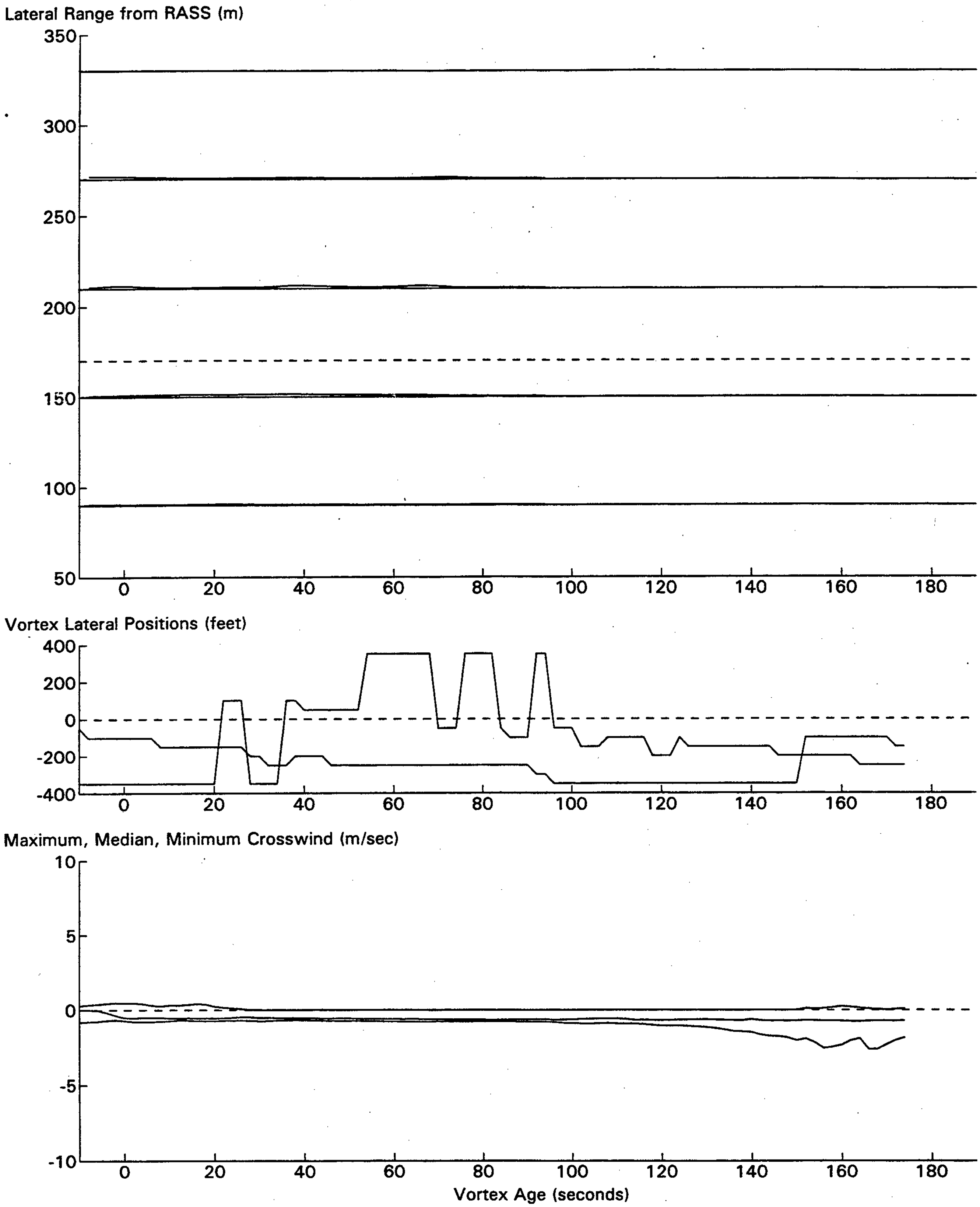

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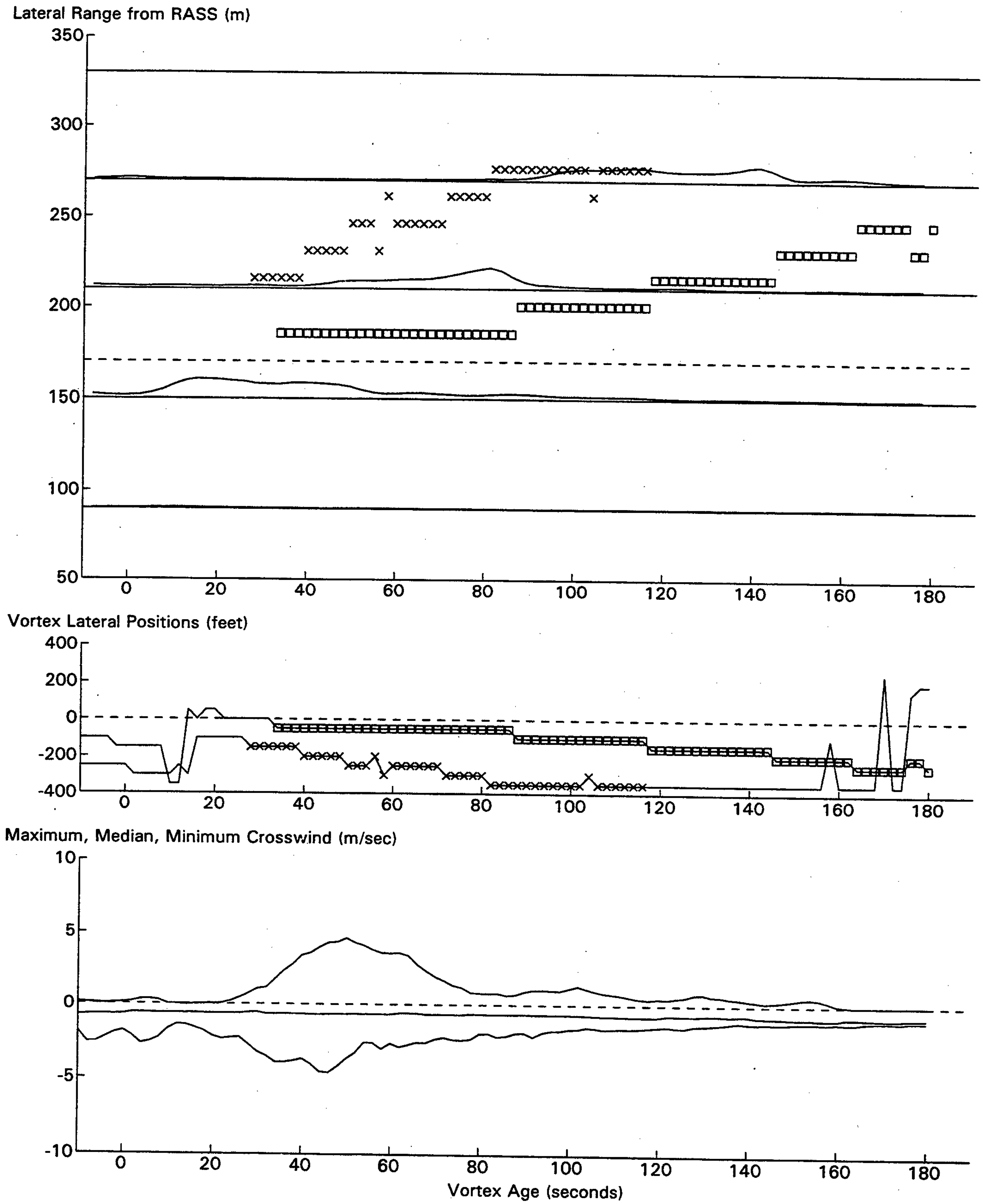

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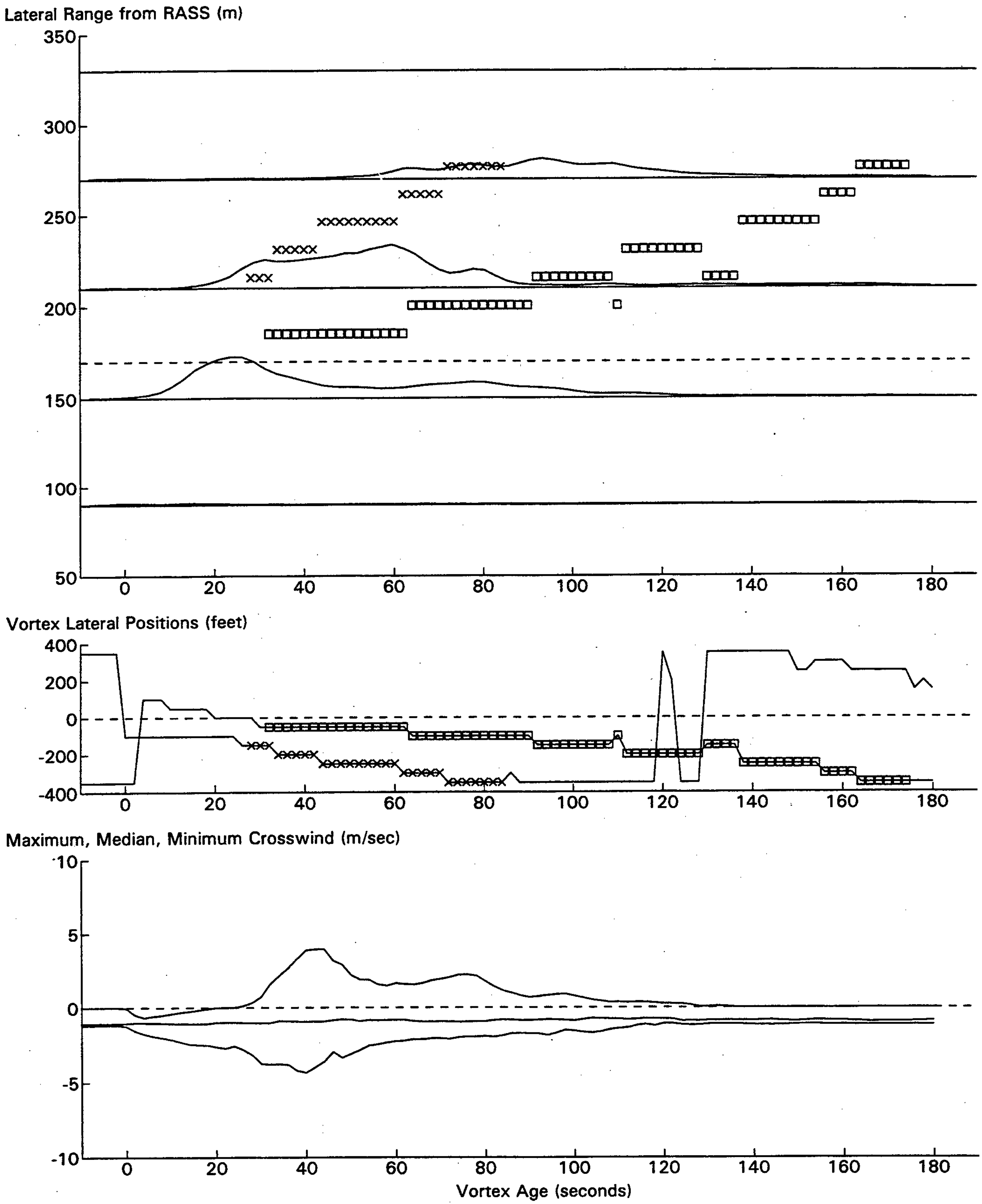

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